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McColloch

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(54) **METHODS, APPARATUSES AND SYSTEMS FOR BLIND MATING MULTI-OPTICAL FIBER CONNECTOR MODULES**

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G02B 6/38 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/3885*** (2013.01); ***G02B 6/3883*** (2013.01)

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USPC 385/53, 55, 56, 59, 60
See application file for complete search history.

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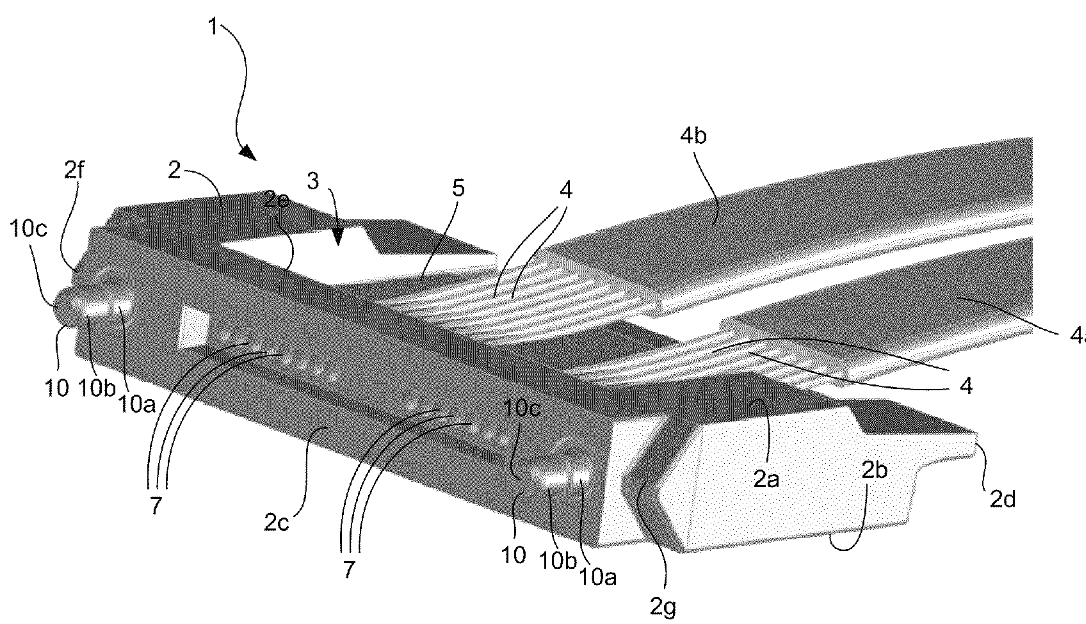
Primary Examiner — Jennifer Doan

(57) **ABSTRACT**

Apparatuses, systems and methods are provided that enable N female multi-optical fiber connector modules disposed on a first structure to be simultaneously blind mated with N male multi-optical fiber connector modules disposed on a second structure, where N is a positive integer that is equal to or greater than one. Enabling the male and female multi-optical fiber connector modules to blind mate with one another obviates the need to individually interconnect the modules with optical cables. Each module is mounted on either a male or female socket, which, in turn, is mounted on the first or second structure. The first structure may be, for example, a rack having at least one slot configured to receive a server box, in which case the second structure is the server box itself.

20 Claims, 11 Drawing Sheets



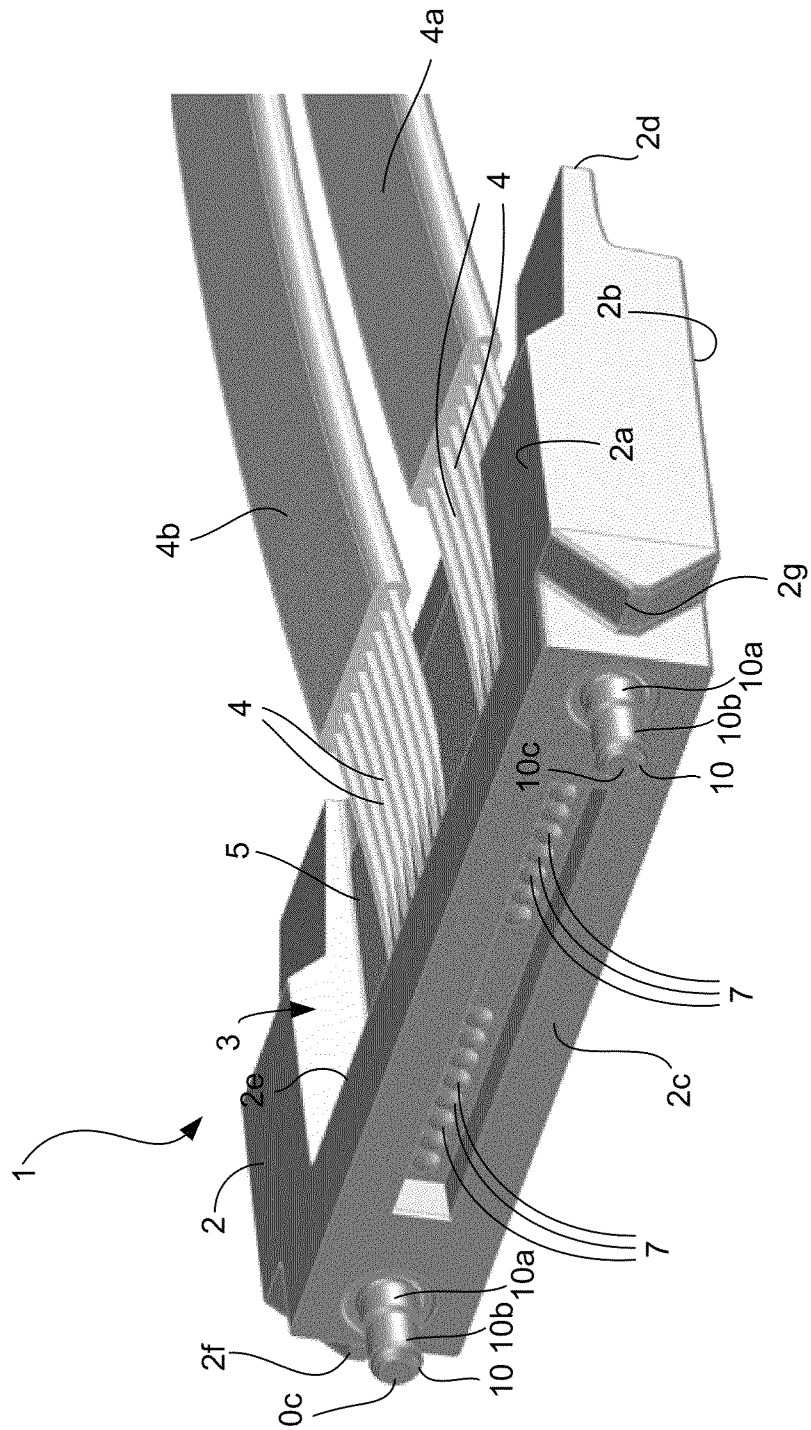


FIG. 1

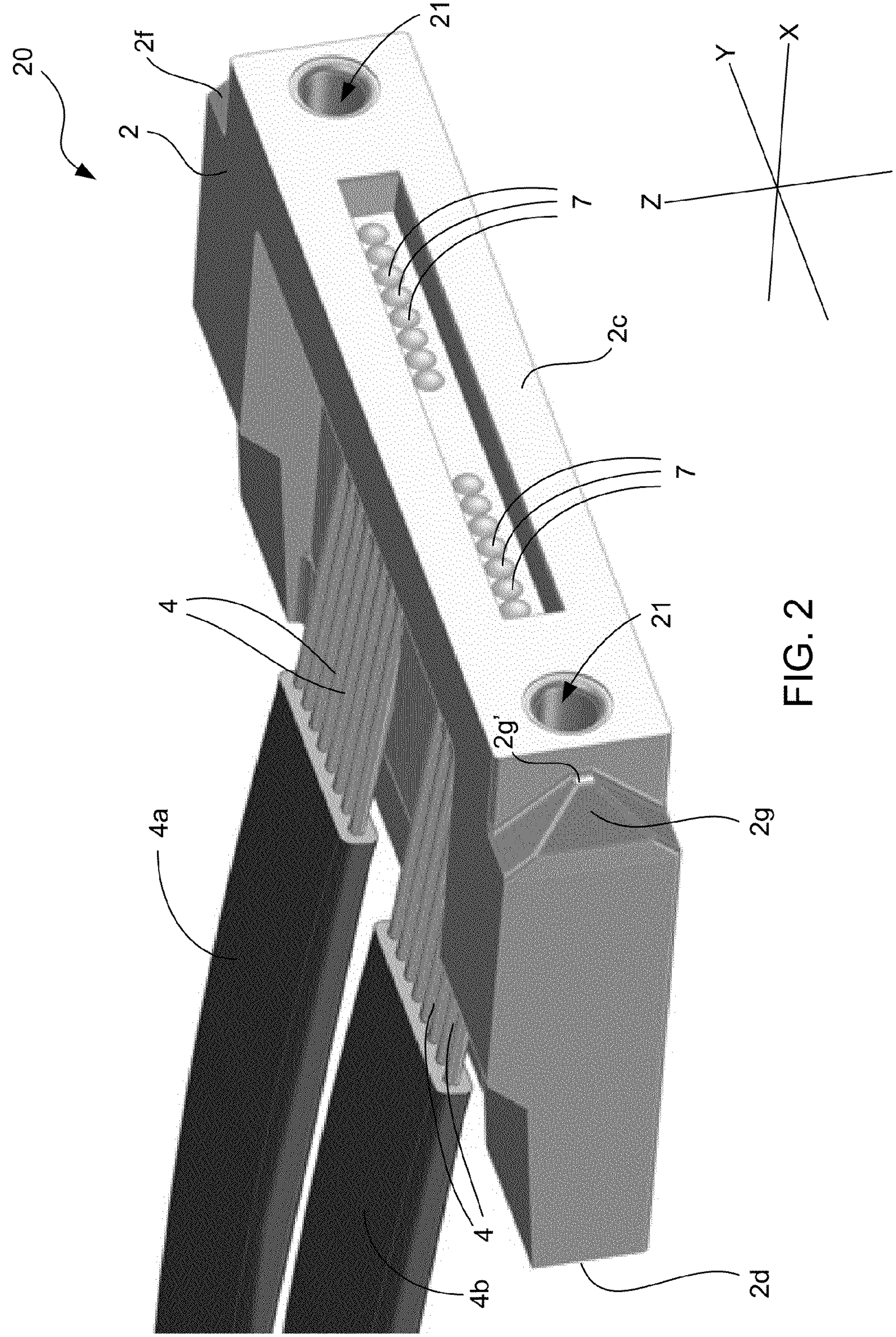


FIG. 2

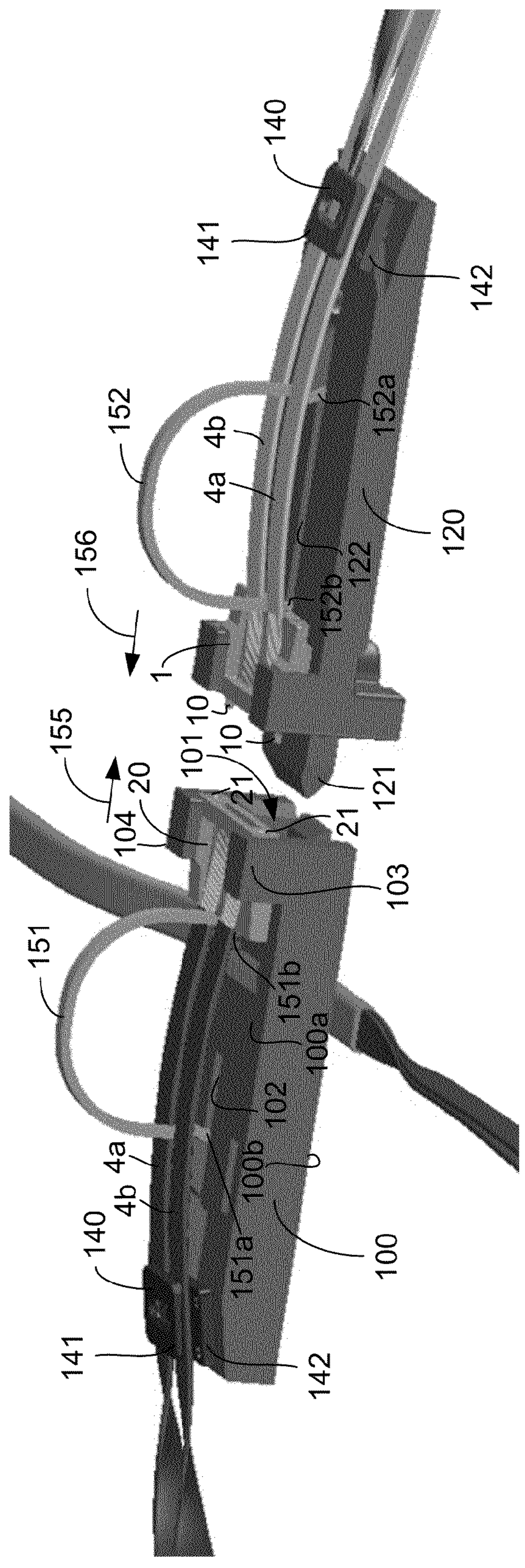

140
141
142
152
152a
4b
4a
120
122
156
152b
1
10
155
101
20
21
104
121
103
151
151b
100a
102
100b
151a
100

FIG. 3

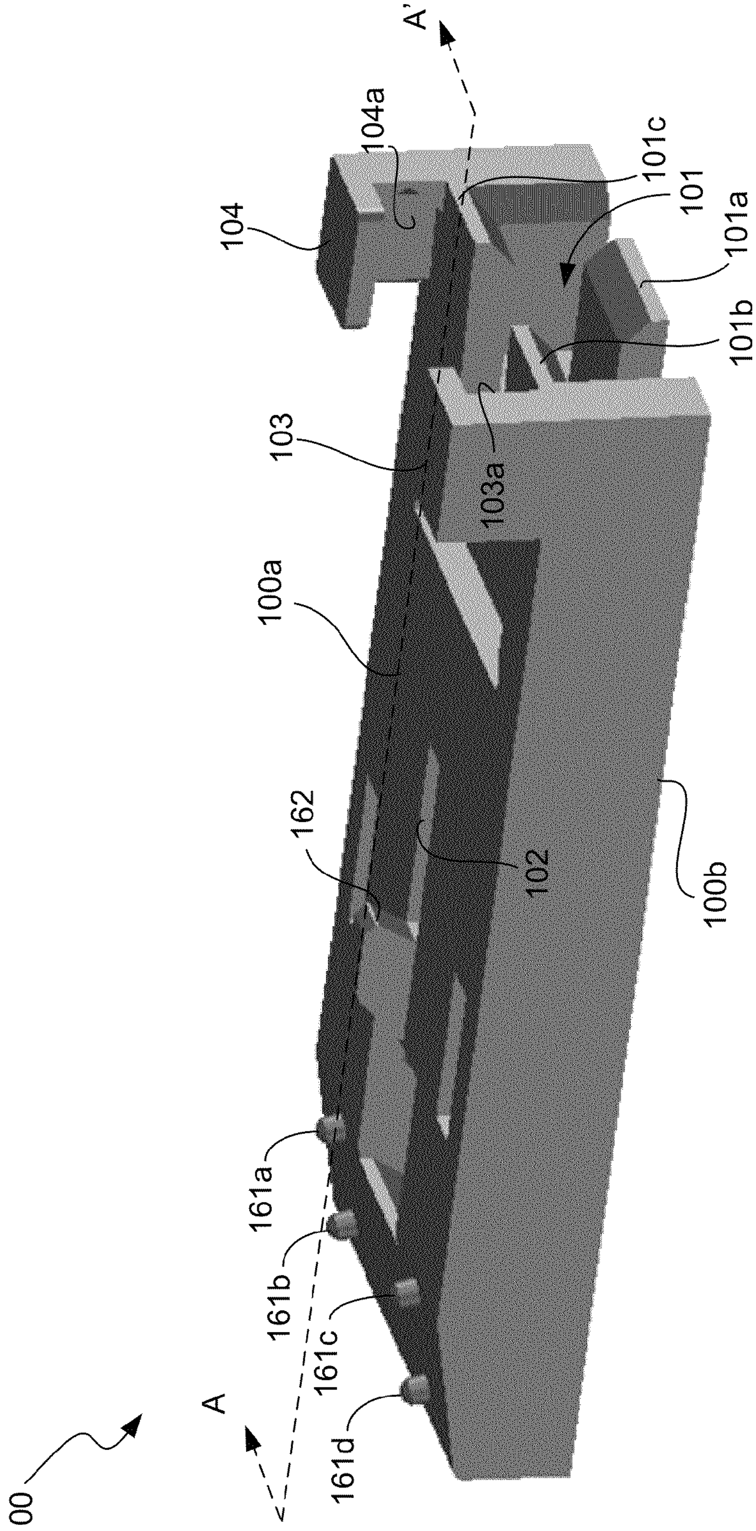

A'
104a
101c
104
101
101a
101b
103
103a
100a
162
102
100b
161a
161b
161c
161d
A
100

FIG. 4

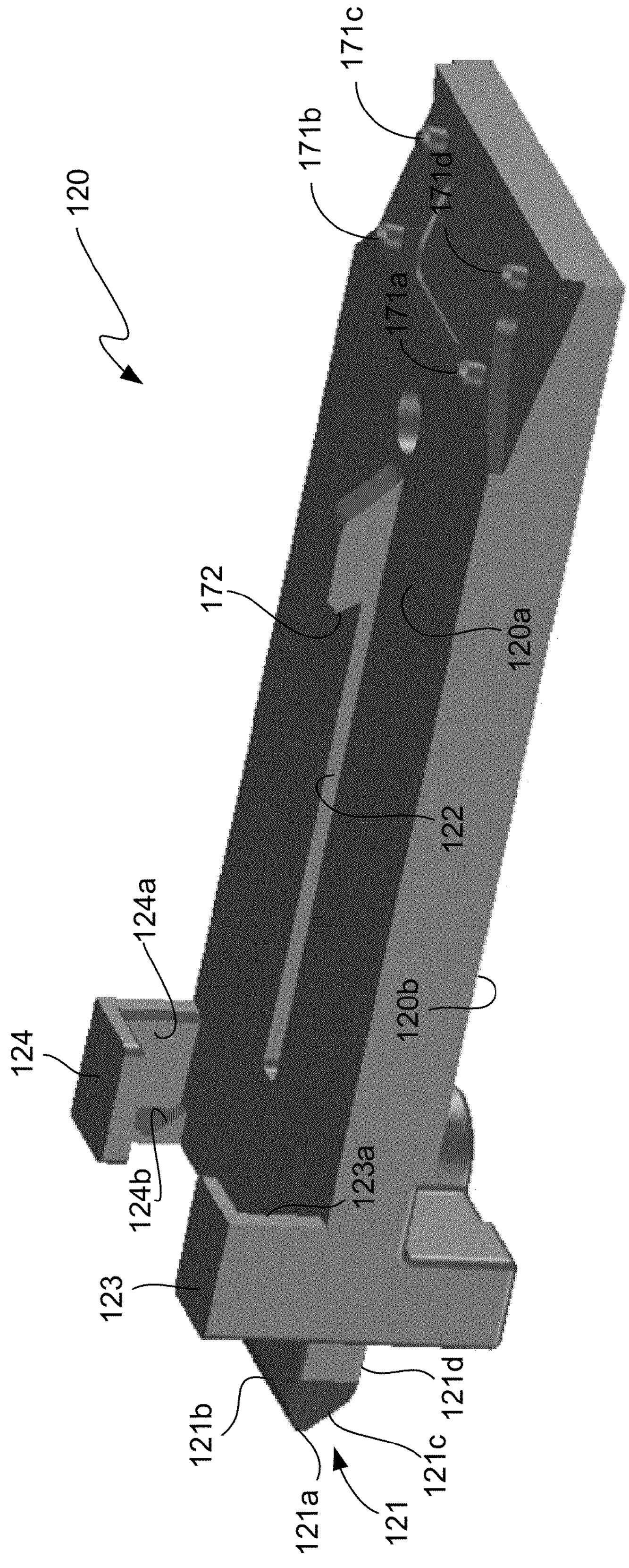
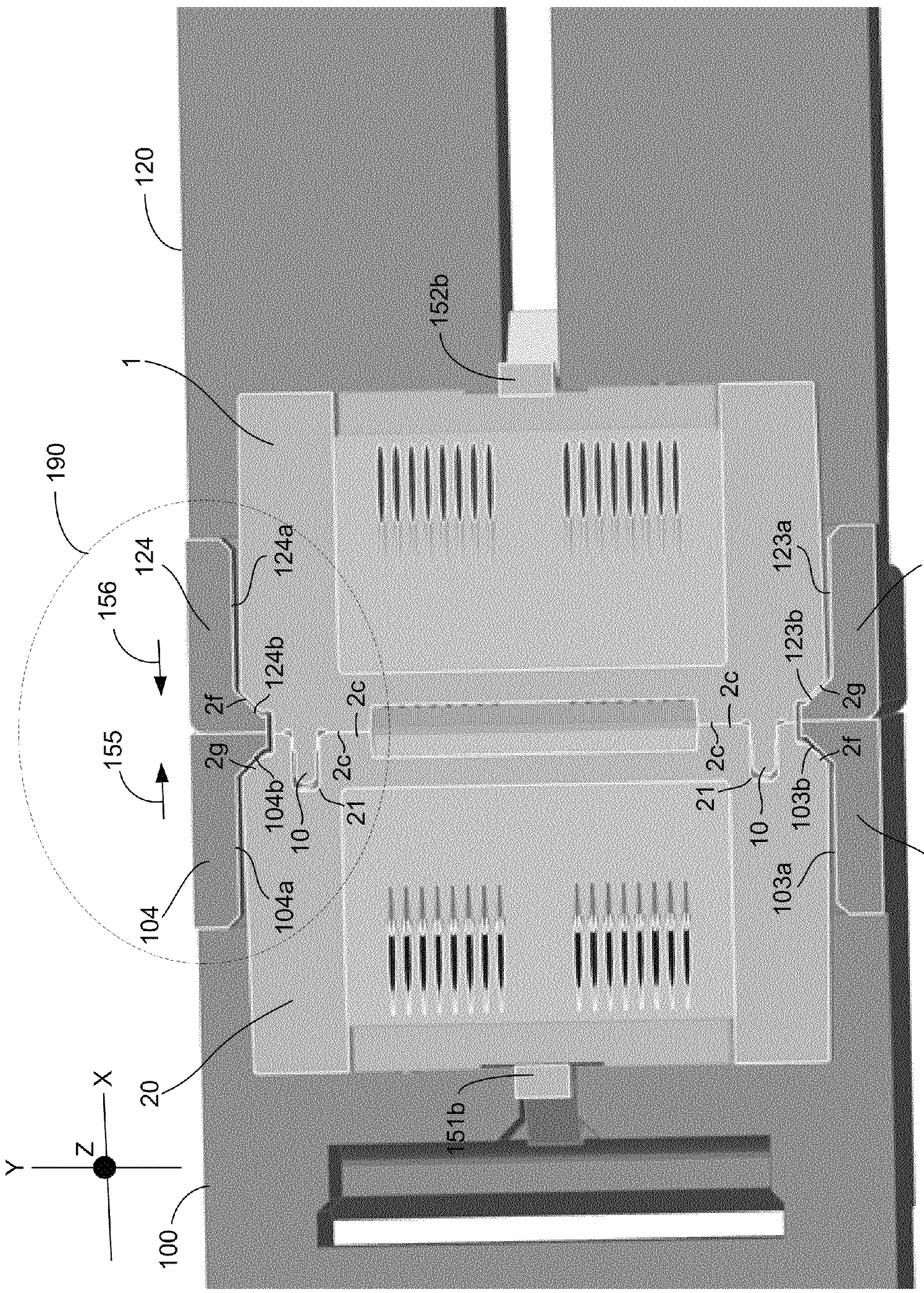

120
171c
171b
171d
171a
172
120a
122
124a
124
120b
124b
123a
123
121d
121b
121c
121a
121

FIG. 5



120
152b
1
190
124
124a
156
124b
2f
2c
2g
155
104b
10
21
104
104a
20
151b
X
Y
Z
100
123a
123
123b
2g
2c
2c
21
10
2f
103b
103
103a

FIG. 6

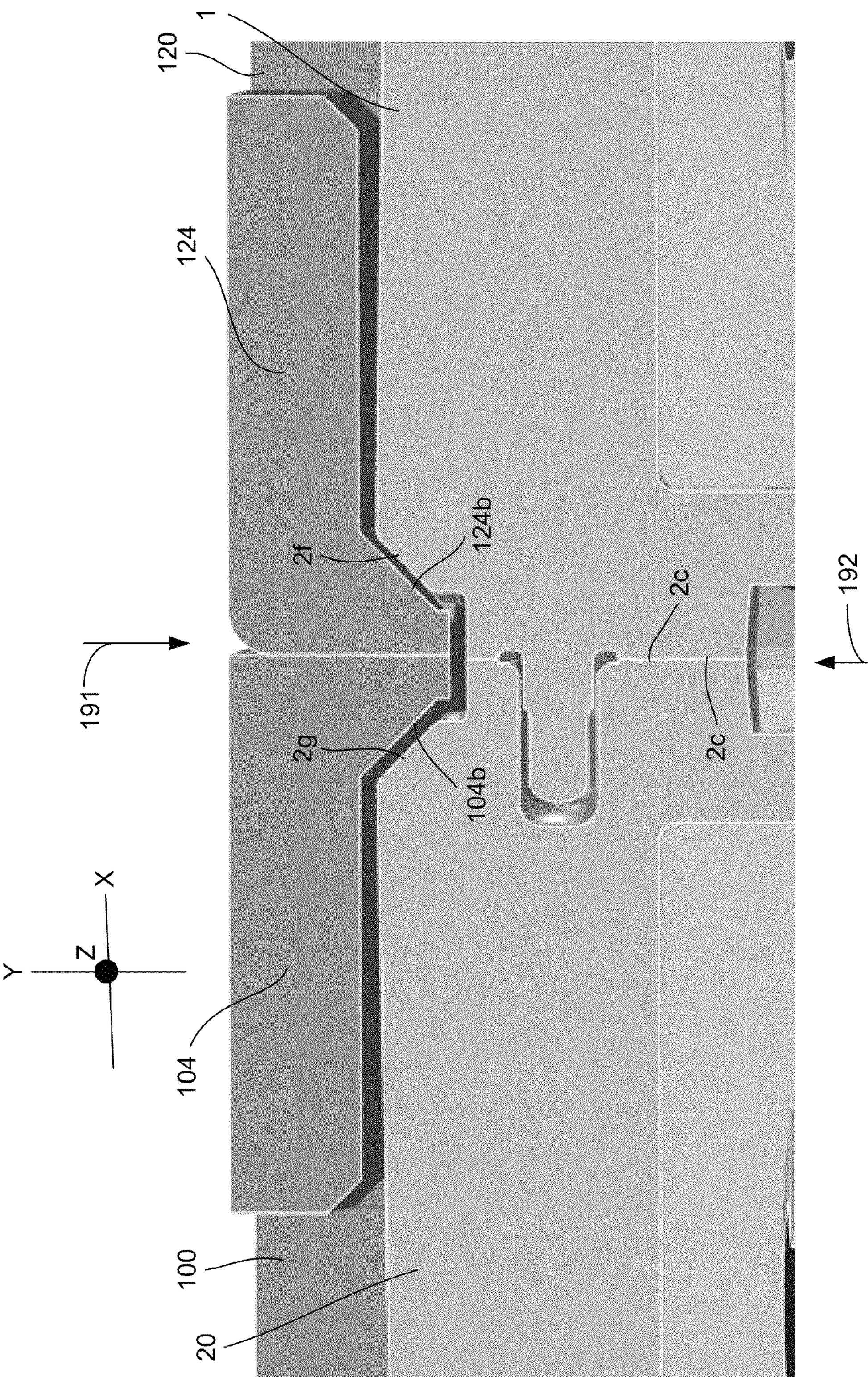


FIG. 7

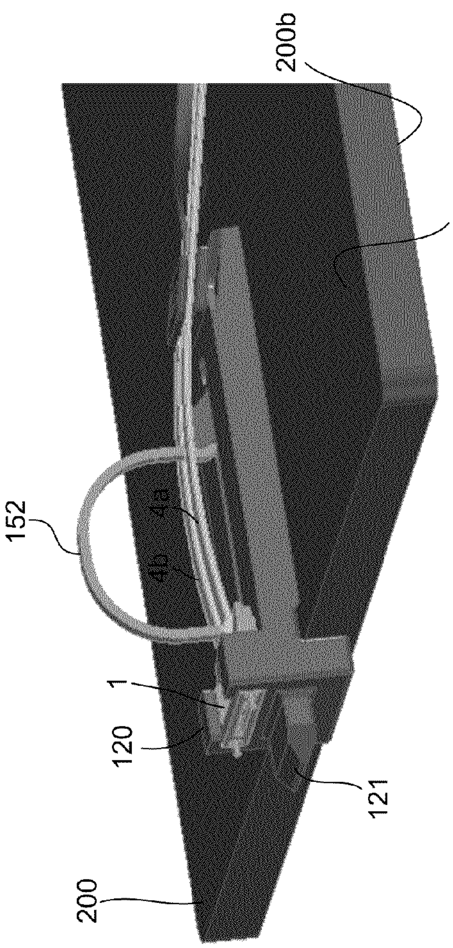


FIG. 8A

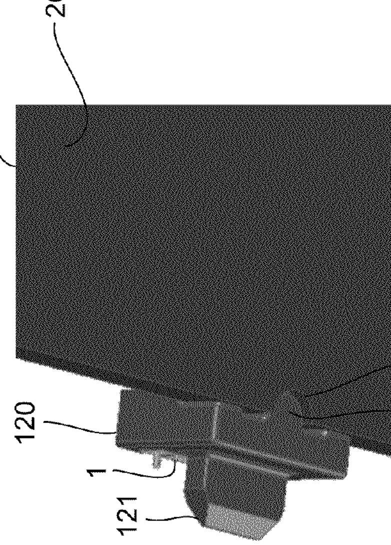


FIG. 8B

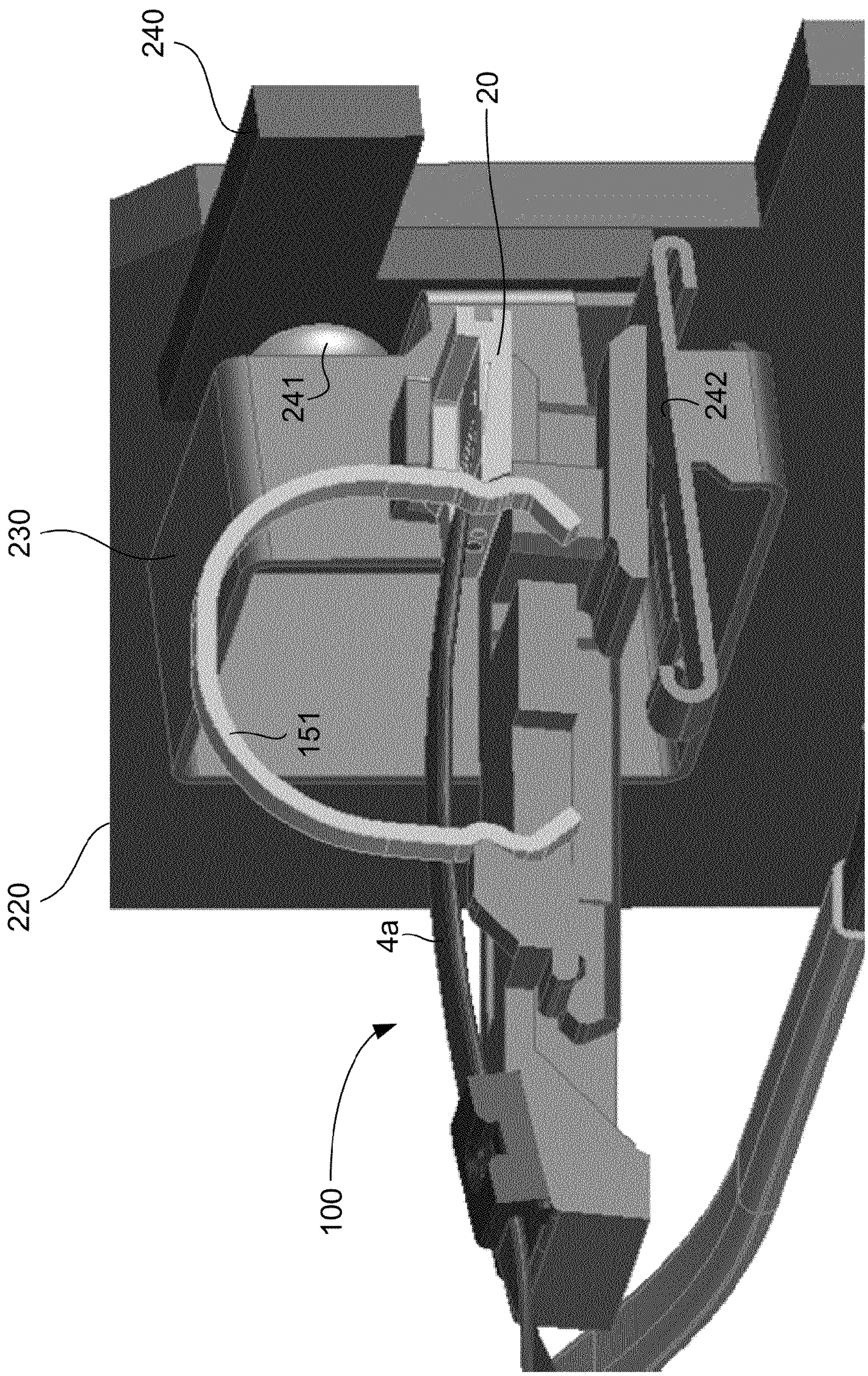


FIG. 9A

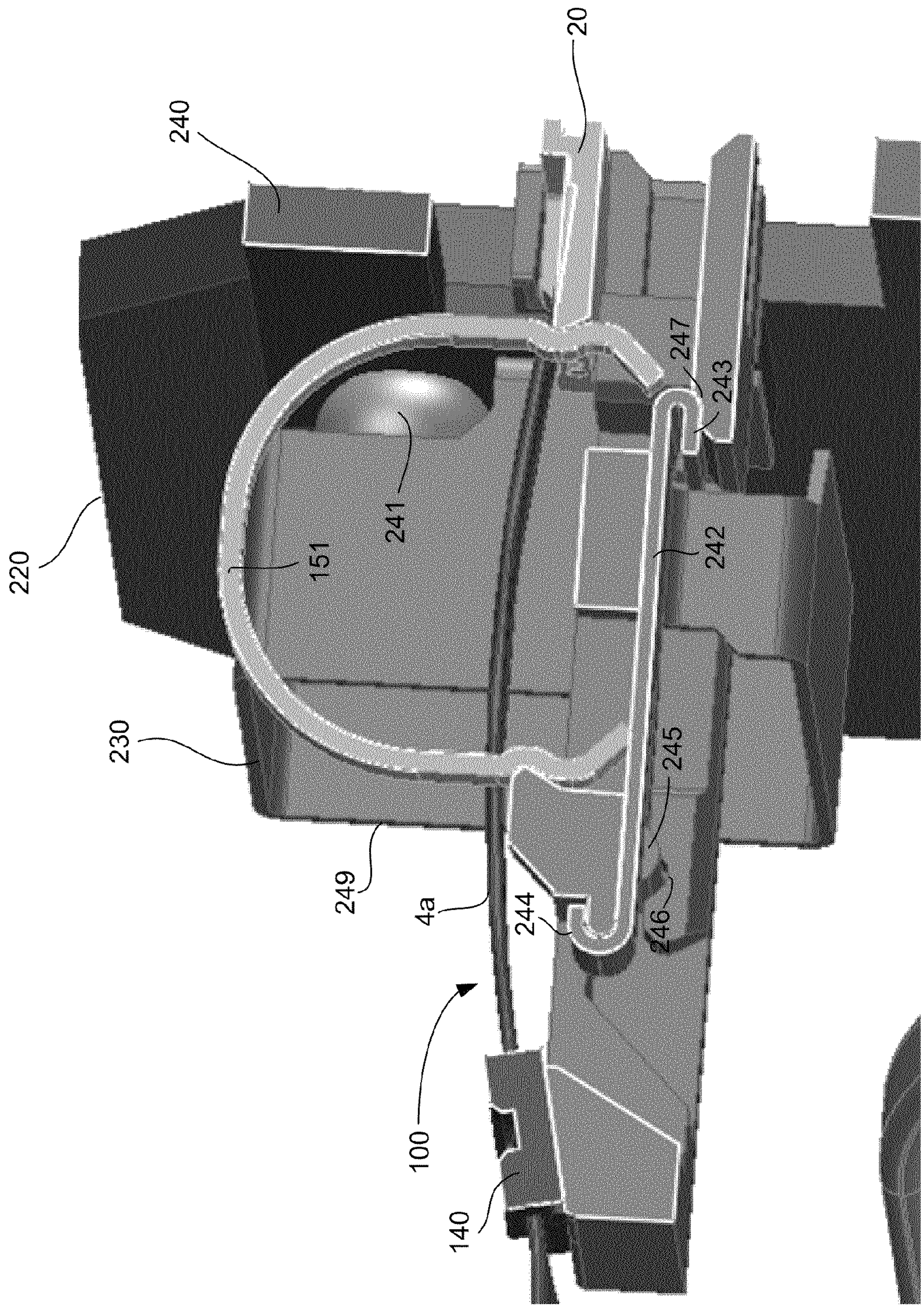


FIG. 9B

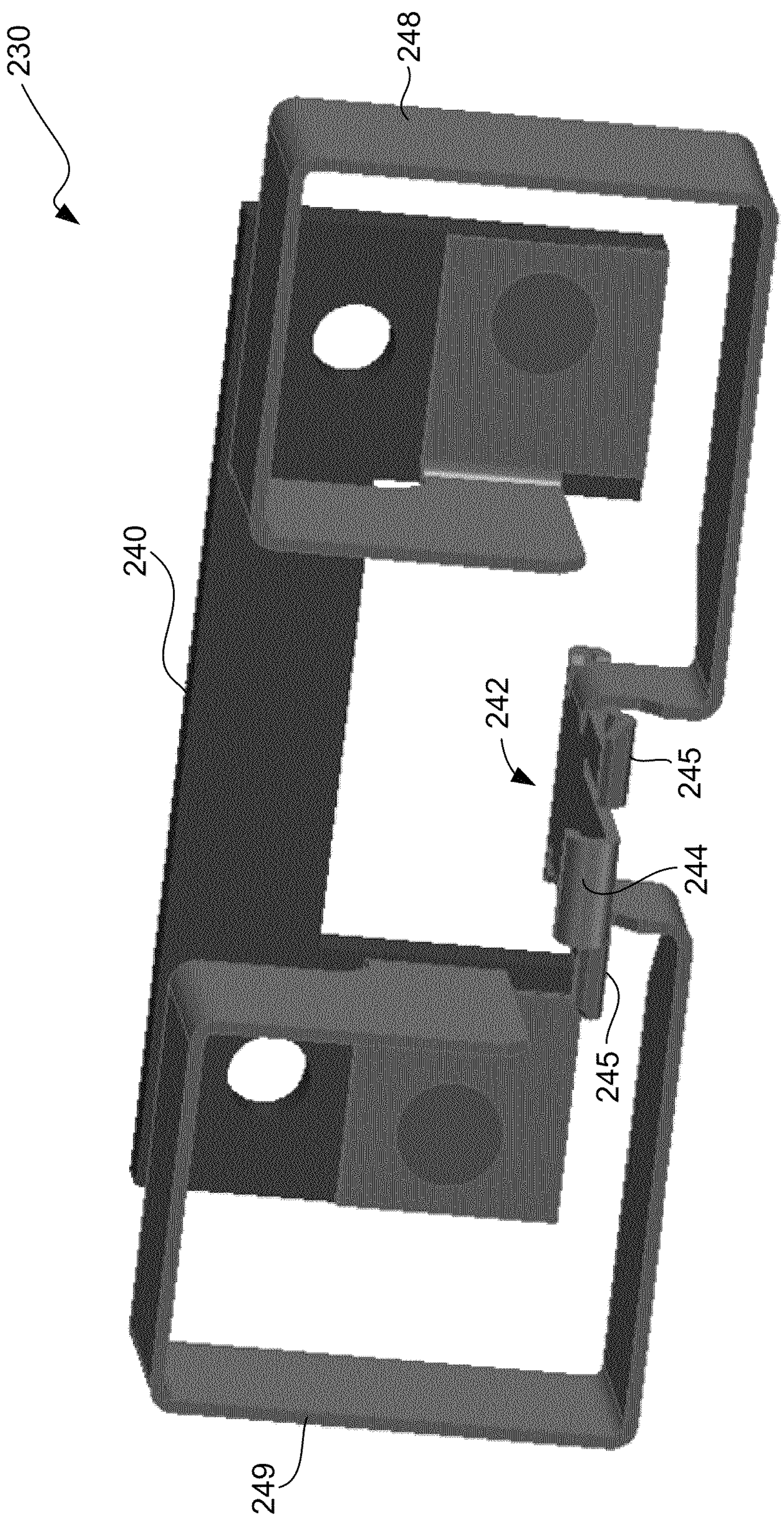


FIG. 10

METHODS, APPARATUSES AND SYSTEMS FOR BLIND MATING MULTI-OPTICAL FIBER CONNECTOR MODULES

TECHNICAL FIELD OF THE INVENTION

The invention relates to optical communications. More particularly, the invention relates to methods and systems for blind mating multi-optical fiber connector modules.

BACKGROUND OF THE INVENTION

Multi-optical fiber connector modules are used to mechanically couple the ends of a plurality of optical fibers to a parallel optical communications module that has a plurality of optical channels. The parallel optical communications module may be a parallel optical transceiver module having both transmit and receive optical channels, a parallel optical transmitter module having only transmit optical channels, or a parallel optical receiver module having only receive optical channels. A typical multi-optical fiber connector module includes an optics system that couples light between the ends of the optical fibers and respective optoelectronic devices that are contained within the parallel optical communications module. For transmit optical channels, the optoelectronic devices are electrical-to-optical converters such as laser diodes or light-emitting diodes (LEDs). For receive optical channels, the optoelectronic devices are optical-to-electrical converters such as photodiodes.

The multi-optical fiber connector modules and the parallel optical communications modules typically have mating features on them that allow the multi-modules to be fixedly or removably mechanically coupled (i.e., mated) with one another. A variety of multi-optical fiber connector modules and parallel optical communications modules exist in the market today that are designed to mate with one another in a way that optically aligns the optical pathways between the ends of the optical fibers and the respective optoelectronic devices to enable optical data signals to be coupled between ends of the optical fibers and the respective optoelectronic devices. In designing and manufacturing the multi-optical fiber connector modules and the corresponding parallel optical communications modules, great care is taken to ensure that once the modules are mated together very precise optical alignment exists along the optical pathways.

A variety of passive and active optical alignment techniques and tools are used today to provide the precise optical alignment that is needed to prevent unacceptable optical losses from occurring. Unacceptable optical losses lead to signal degradation, which can lead to an unacceptable bit error rate (BER). When the multi-optical fiber connector modules and the corresponding parallel optical communications modules are manufactured, the manufacturing tolerances typically must be extremely tight in order to ensure that very precise optical alignment exists along the optical pathways when the modules are mated with one another in their ultimate relative positions and orientations. Otherwise, the optical alignment along the optical pathways will not have sufficient precision to prevent unacceptable optical losses from occurring. However, manufacturing the modules with very tight mechanical tolerances increases manufacturing costs, which increases the overall costs of the modules. In addition, the need to achieve very tight mechanical tolerances can lead to a decrease in yield for the modules, which also increases the overall costs of the modules.

Many connector modules are designed and manufactured to include passive alignment features, such as key/keyway mating features, which guide the modules into optical alignment with another mating module or receptacle as they are mechanically coupled together. For example, the opening in a receptacle guides a mating connector module into course alignment with the receptacle and then passive alignment features in the receptacle and on the connector module then mate to bring the optical pathways of the connector module into fine, or precise, optical alignment with the optical pathways of the receptacle. While such passive alignment features generally work well for their intended purposes, they are not suitable for simultaneous blind mating of multiple connector modules with multiple respective mating modules or receptacles.

For example, for a server box that has multiple multi-fiber connector modules disposed on it that must be mated with corresponding multi-fiber connector modules disposed on a printed circuit board (PCB) of a backplane, the connector modules disposed on the server box are individually manually interconnected with the respective connector modules disposed on the backplane by optical cables. As examples, in the case of LC optical connectors, an LC-to-LC optical cable is used to make the interconnection whereas in the case of MTP® optical connectors, an MTP-to-MTP optical cable is used to make the interconnection. Making these interconnections can be a difficult and time-consuming task.

A need exists for methods, apparatuses and systems that enable a plurality of multi-optical fiber connector modules disposed on one structure to be simultaneously blind mated with another plurality of connector modules disposed on another structure, thereby obviating the need to individually manually interconnect the connector modules.

SUMMARY OF THE INVENTION

The invention is directed to apparatuses, systems and methods for blind mating multi-optical fiber connector modules. The apparatus comprises a first socket having a first multi-optical fiber connector module mounted thereon. The first socket is adapted to mate with a second socket having a second multi-optical fiber connector module mounted thereon such that mating of the first and second sockets with one another results in mating of the first and second connector modules with one another. The first socket comprises a first socket housing having at least a first passive coarse alignment feature formed thereon. The first socket housing has at least an upper surface, a lower surface, a first end, and a second end. The first multi-optical fiber connector module is mounted on the upper surface of the first socket housing in a predetermined position and orientation relative to the first socket housing. The first multi-optical fiber connector module has a first connector module housing that has at least a first passive fine alignment feature formed thereon.

The first passive coarse alignment feature of the first socket housing is configured to engage and ultimately fully mate with a second passive coarse alignment feature formed on a second socket housing of the second socket. Engagement of the first and second passive coarse alignment features with one another brings the first and second passive fine alignment features of the first and second connector module housings into coarse alignment with one another. Full mating of the first and second passive coarse alignment features with one another results in full blind mating of the first and second fine alignment features with one another to place the first and second fine alignment features in a fully-mated state. When the first and second fine alignment features are in the fully-mated state, optical pathways of the first connector module are in precise alignment with respective optical pathways of the second connector module.

The system comprises a first structure, a mounting frame secured to the first structure, a first socket mounted on the mounting frame, a first multi-optical fiber connector module mounted on an upper surface of the housing of the first socket, a first plurality of optical fibers having first ends that are secured to the housing of the first multi-optical fiber connector module, a second structure, a second socket mounted on the second structure, a second multi-optical fiber connector module mounted on an upper surface of a housing of the second socket, and a second plurality of optical fibers having first ends that are secured to the housing of the second multi-optical fiber connector module.

The mounting frame has spring properties. The housing of the first socket has at least an upper surface, a lower surface, a first end, and a second end. The housing of the first socket has at least a first passive coarse alignment feature thereon. The housing of the second socket has an upper surface, a lower surface, a first end and a second end. The housing of the second socket has a second passive coarse alignment feature thereon that is mated with the first passive coarse alignment feature. The housing of the first multi-optical fiber connector module has at least a first passive fine alignment feature thereon. The housing of the second multi-optical fiber connector module has at least a second passive fine alignment feature thereon that blind mates with the first passive fine alignment feature when the first and second passive coarse alignment features mate with one another. When the first and second fine alignment features are in the fully-mated state, optical pathways of the first connector module are in precise alignment with respective optical pathways of the second connector module.

These and other features and advantages of the invention will become apparent from the following description, drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a perspective view of the male multi-optical fiber connector module in accordance with an illustrative embodiment.

FIG. **2** illustrates a perspective view of the female multi-optical fiber connector module **20** designed to mate with the male multi-optical fiber connector module **1** shown in FIG. **1**.

FIG. **3** illustrates a perspective view of a female socket on which the female multi-optical fiber connector module shown in FIG. **2** is mounted about to be mated with a male socket on which the male multi-optical fiber connector module shown in FIG. **1** is mounted.

FIG. **4** illustrates a perspective view of the female socket shown in FIG. **3** with the module, the cleave holder and the spring removed.

FIG. **5** illustrates a perspective view of the male socket shown in FIG. **3** with the module, the cleave holder and the spring removed.

FIG. **6** illustrates a top view of the sockets and the modules shown in FIG. **3** in the fully-mated state.

FIG. **7** illustrates a top perspective view of an expanded portion of the view shown in FIG. **6** within the dashed circle labeled with reference numeral **190**.

FIGS. **8**A and **8**B are top and bottom perspective views, respectively, of the male socket shown in FIGS. **3** and **5** mounted on a PCB of a box (not shown) that is designed to be inserted into a slot (not shown) of a rack (not shown).

FIGS. **9**A and **9**B illustrate side cross-sectional perspective views of a cross bar of a rack (not shown) having a mounting frame secured thereto by a bridle of the mounting frame, and wherein the female socket shown in FIGS. **3** and **4** is shown mounted on the mounting frame; the side cross-sectional views of the female socket shown in FIGS. **9**A and **9**B are taken along line A-A' of FIG. **4**; FIG. **9**A shows the female socket shown in FIG. **3** in the process of being snapped into a mounting spring socket of a mounting frame; FIG. **9**B shows the female socket after it has been snapped into place in the spring socket.

FIG. **10** is a perspective view of the mounting frame shown in FIGS. **9**A and **9**B with the female socket and the cross bar removed.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

In accordance with embodiments of the invention, apparatuses, systems and methods are provided that enable N female multi-optical fiber connector modules disposed on a first structure to be simultaneously blind mated with N male multi-optical fiber connector modules disposed on a second structure, where N is a positive integer that is equal to or greater than one. Enabling the male and female multi-optical fiber connector modules to blind mate with one another obviates the need to individually interconnect the modules with optical cables. Each module is mounted on either a male or female socket, which, in turn, is mounted on the first or second structure. The first structure may be, for example, a rack having at least one slot configured to receive a server box, in which case the second structure is the server box itself.

As the first and second structures are brought into engagement with one another, passive coarse alignment features of the male and female sockets begin to mate with one another. The act of mating the passive coarse alignment features of the male and female sockets with one another causes passive fine alignment features of the male and female connector modules to be brought into coarse alignment with one another. Once the passive fine alignment features of the male and female connector modules have been brought into coarse alignment with one another, the continued mating of the passive coarse alignment features of the male and female sockets causes the passive fine alignment features of the male and female connector modules to engage one another. As the male and female sockets are moved into their fully-mated configuration, the passive fine alignment features of the male and female connector modules fully mate with one another. Once the male and female connector modules are in their fully-mated configuration such that the fine alignment features are fully mated with one another, the respective connector modules are finely aligned with one another such that their respective optical pathways are in precise optical alignment with one another. Blind mating the connector modules with one another in this way eliminates the need to use optical cables or the like to optical interconnect the respective connector modules.

Prior to describing the male and female sockets on which the multi-optical fiber connector modules are mounted and the structures on which the male and female sockets are mounted, examples of male and female multi-optical fiber connector modules that are suitable for use with the sockets will be described.

Like reference numbers in the figures represent like elements, features, or components. The features in the drawings are not necessarily drawn to scale. It should be noted that the invention is not limited with respect to the multi-optical fiber connector modules that are used with the sockets and that the multi-optical fiber connector modules being described herein are merely examples of modules that are suitable for use with the sockets.

FIG. **1** illustrates a perspective view of the male multi-optical fiber connector module **1** in accordance with an illustrative embodiment. The male multi-optical fiber connector module **1** comprises a module housing **2** having an upper surface **2***a*, a lower surface **2***b* a front surface **2***c*, a back end **2***d*. A cavity **3** is formed in the upper surface **2***a* for receiving ends of a plurality of optical fibers **4** of two optical fiber cables **4***a* and **4***b*. In accordance with this illustrative embodiment, there are a total of sixteen optical fibers **4** and the multi-fiber connector module **1** has sixteen respective optical pathways, although the invention is not limited with respect to the number of optical fibers that are connected to the connector module **1** or the number of optical channels that are provided in the connector module **1**. The module housing **2** is typically a molded, unitary plastic part, although the invention is not limited with respect to the composition of the module housing **2**.

The multi-optical fiber connector module **1** has features that are similar or identical to features of a multi-optical fiber connector module that is disclosed in U.S. Pat. No. 7,543,994 (hereinafter the '994 patent) and U.S. Pat. No. 7,553,091 (hereinafter the '091 patent), which are assigned to the assignee of the present application and which are incorporated by reference herein in their entireties.

As can be seen in FIG. **1**, the upper surface **2***a* of the module housing **2** has a cavity **3** formed therein. The cavity **3** functions as an optical fiber holding chamber for holding the ends of the optical fibers **4**. The cavity **3** has a lower surface in which a plurality of grooves (not shown) are formed. Each groove is V-shaped. Prior to securing the ends of the optical fibers **4** within the cavity **3**, each optical fiber **4** is cleaved and then a portion of the jacket is removed, leaving an unjacketed fiber end portion. The unjacketed fiber end portions of the fibers **4** are positioned within the respective grooves of the cavity **3**. A refractive index matching (RIM) epoxy **5** that is transparent to the primary wavelength of the optical signals being carried on the optical fibers **4** is dispensed into the cavity **3**. The RIM epoxy **5** fills any imperfections in the cleaved ends of the optical fibers **4**, thereby making the joints transparent to the optical beams so that no internal reflection occurs at this boundary. When the epoxy **5** is dispensed into the cavity **3**, it flows between, and is in contact with, the bottom and side walls of the cavity **3** and with the unjacketed fiber end portions. When the epoxy **5** cures and becomes hardened, it fixedly secures the ends of the unjacketed fiber end portions within the respective V-shaped grooves.

The ends of the unjacketed fiber end portions are adjacent to, or in contact with, the wall **2***e* of the module housing **2**. The wall **2***e* of the module housing **2** is one of the side walls that define the cavity **3**. Respective openings are formed in the module housing **2** that extend in the axial directions of the grooves from the cavity **3** through the wall **2***e* and through a front surface **2***c* of the module housing **2**. Within these openings, respective collimating lenses **7** are disposed in the front surface **2***c* of the module housing **2**. First and second passive fine alignment features **10** extend from the front surface **2***c* of the module housing **2**. The passive fine alignment features **10** are identical in structure to one another and have stepped cylindrical shapes made up of first and second cylindrical portions **10***a* and **10***b*, where the first cylindrical portion **10***a* has a diameter that is greater than a diameter of the second cylindrical portion **10***b*. The passive fine alignment features **10** are rounded where they transition from the second cylindrical portions **10***b* to their ends **10***c*. The passive fine alignment features **10** are designed to mate with respective openings formed in another module (not shown), as will be described below in more detail.

FIG. **2** illustrates a perspective view of the female multi-optical fiber connector module **20** designed to mate with the male multi-optical fiber connector module **1** shown in FIG. **1**. The module **20** has a module housing **2** that is identical to the module housing **2** shown in FIG. **1** except that the module housing **2** shown in FIG. **2** has openings **21** formed therein that are complementary in shape to the passive fine alignment features **10** of the module **1** shown in FIG. **1**. As will be described below in more detail, when the alignment features **10** of the module **1** are aligned with the respective alignment features **21** of the modules **20** and the surfaces **2***c* of the modules **1** and **20** are brought into contact with one another, the alignment features **10** mate with the respective alignment features **21**. When the modules **1** and **20** are in this fully-mated configuration, the collimating lenses **7** of the modules **1** and **20** are in precise optical alignment with one another and the optical pathways (not shown) of the modules **1** and **20** are in precise optical alignment with one another. Thus, the mating of the passive fine alignment features **10** and **21** effectuates the aforementioned fine alignment process, but the aforementioned coarse alignment process is effectuated by engagement of respective passive coarse alignment features (not shown) that are disposed on sockets (not shown) on which the modules **1** and **20** are mounted, as will now be described.

FIG. **3** illustrates a perspective view of a female socket **100**, on which the female multi-optical fiber connector module **20** shown in FIG. **2** is mounted, about to be mated with a male socket **120**, on which the male multi-optical fiber connector module **1** shown in FIG. **1** is mounted. The female socket **100** has a receptacle **101** formed therein that is shaped and sized to mate with a tongue **121** of the male socket **120**. Engagement of the tongue **121** with the receptacle **101** brings the multi-optical fiber connector modules **1** and **20** into coarse alignment with one another such that the passive fine alignment features **10** and **21** of the modules **1** and **29**, respectively, begin to engage one another. As the tongue **121** and the receptacle **101** continue to engage one another, the passive fine alignment features **10** and **21** of the modules **1** and **20**, respectively, continue to engage one another to bring the modules **1** and **20** into fine alignment with each other. Thus, full mating of the tongue **121** and the receptacle **101** results in full mating of the modules fine alignment features **10** and **21** to bring the modules **1** and **20** into precise optical alignment with one another.

Providing the passive fine alignment features **10** with the stepped cylindrical shape shown in FIG. **1** provides some advantages over using long tapered pins. Long tapered pins being inserted into the respective reciprocally-shaped tapered openings have a tendency to stick due to the nearly-continuous contact that occurs between the surfaces of the pins and the respective openings as they engage one another. If sticking occurs, it is possible that the respective passive fine alignment features will not fully engage one another, which can result in less than perfect misalignment. One advantage of the stepped passive fine alignment features **10** is that there is less of a tendency to stick during insertion into the respective openings due to there being less surface-to-surface contact during insertion. This feature ensures that full mechanical coupling will occur, which ensures that precise optical alignment will be achieved. Another advantage is that the stepped cylindrical shapes are easier and less costly to manufacture than tapered shapes. As stated above, however, the invention is not limited with respect to the shapes and configurations of the modules **1** and **20**.

In the illustrative embodiment shown in FIG. **3**, the sockets **100** and **120** also have respective cleave holders **140** mounted thereon that are identical in structure and dimensions. In accordance with an illustrative embodiment, the cleave holder **140** is secured to the fibers **4** before the modules **1** and **20** are secured to the ends of the fibers **4** and is used to hold the fibers **4** as they are being cleaved to desired lengths and stripped of their jackets. The cleave holder **140** remains secured to the fibers **4** after the modules **1** and **20** have been assembled and secured to the stripped and cleaved ends (not shown) of the fibers **4**. The cleave holder **140** typically comprises a molded plastic body having an upper portion **141** and a lower portion **142** that are mechanically coupled to one another. One or both of the upper and lower portions **141** and **142** has grooves formed in lower and upper surfaces thereof, respectively. Length-wise portions of the fibers **4** are laid in the grooves and secured therein.

With the fibers **4** fixedly secured in position within the cleave holder **140**, and with the cleave holder body **141** mounted on a stripper and cleaver tool, the fibers **4** are stripped and the ends are cleaved with very high precision such that the length of the fibers **4** from a particular location in the cleave holder **140** to the fiber end faces is equal to a very precise, predetermined value. Once the fibers **4** have been secured in place within the cleave holders **140**, the cleave holders **140** are mounted on the sockets **100** and **120** such that pins (not shown) disposed on the sockets **100** and **120** are received in respective holes (not shown) of the lower portion **142** of the cleave holders **140**. An adhesive material such as glue may be used to fixedly secure the cleave holders **140** to the sockets **100** and **120**. The cleave holders **140** provide strain relief for the fibers **4**.

Springs **151** and **152** are mechanically coupled to the sockets **100** and **120**, respectively, via slots **102** and **122**, respectively, formed in the sockets **100** and **120**, respectively. Proximal ends **151***a* and **152***a* of the springs **151** and **152**, respectively, are immovable whereas distal ends **151***b* and **152***b* of the springs **151** and **152**, respectively, are free to move within the respective slots **102** and **122**. The distal ends **151***b* and **152***b* of the springs **151** and **152** are in contact with the back ends **2***d* (FIGS. **1** and **2**) of the module housings **2**. The forces of the springs **151** and **152** in their loaded states shown in FIG. **3** urge the modules **20** and **1**, respectively in the directions indicated by arrows **155** and **156**, respectively, until the modules **20** and **1** abut tapered stops (not shown) formed in the sockets **100** and **120** that prevent further movement of the modules **20** and **1** in the directions of arrows **155** and **156**, respectively. These tapered stops are described below in more detail.

FIG. **4** illustrates a perspective view of the female socket **100** shown in FIG. **3** with the module **20**, the cleave holder **140** and the spring **151** removed. The receptacle **101** of the socket **100** has alignment features **101***a*, **101***b* and **101***c* therein that define the shape of the receptacle **101**. The alignment feature **101***a*, which defines a bottom of the receptacle **101**, tapers upwardly such that it is smaller in width at the entrance of the receptacle **101** and gradually increases in width to a constant width once inside of the receptacle **101**. The alignment features **101***b* and **101***c* taper downwardly such that they are smaller in width at the entrance of the receptacle **101** and gradually increase in width to a constant width once inside of the receptacle **101**. The manner in which these alignment features **101***b* and **101***c* mate with the tongue **121** of socket **120** shown in FIG. **3** is described below in more detail.

The socket **100** has an upper surface **100***a* and a lower surface **100***b*. A plurality (e.g., four) of pins **161***a*-**161***d* are disposed on the upper surface **100***a* for mating with openings (not shown) formed in the lower portion **142** (FIG. **3**) of the cleave holder **140** (FIG. **3**). The openings that formed in the lower portion **142** of the cleave holder **140** are complementary in shape and size to the shape and size of the pins **161***a*-**161***d*. It can be seen from FIG. **3** that the portions of the fibers **4** that extend in between the cleave holders **140** and the modules **1** and **100** have some slack in them to provide strain relief for the ends of the fibers **4** that are secured to the modules **1** and **100**.

A stop **162** (FIG. **4**) disposed at the back end of the slot **102** abuts the proximal end **151***a* of the spring **151** to prevent the proximal end **151***a* of the spring **151** from moving in the rearward direction of the socket **100** (i.e., in the direction opposite the direction of arrow **155**). This stop **162** enables the spring **151** to be loaded to exert the force on the module **20** that urges the module **20** in the direction of arrow **155**. The module **20** sits on the upper surface **100***a* of the socket **100** and is urged forward by the spring **151** into contact with side arms **103** and **104** of the socket **100**. As will be described below in more detail, the arms **103** and **104** have tapered stops (not shown) formed on their inner walls **103***a* and **104***a* (FIG. **4**) that prevent further forward movement of the module **20** in the direction of arrow **155** (FIG. **3**). The inner walls **103***a* and **104***a* are identical to one another and are complementary in shape to the shapes of side chamfers **2***f* and **2***g* (FIG. **2**) disposed on opposite sides of the module housing **2**. As will be described below in more detail, these tapered stops mate with, but are slightly larger than, the chamfers **2***f* and **2***g* to allow some freedom of movement of the module **20** when it is in the forward position shown in FIG. **3**.

FIG. **5** illustrates a perspective view of the male socket **120** shown in FIG. **3** with the module **1**, the cleave holder **140** and the spring **152** removed. The tongue **121** of the socket **120** constitutes an alignment feature that is complementary in shape and size to the shape and size of the inner surfaces of the receptacle **101** defined by the alignment features **101***a*-**101***c* (FIG. **4**). Starting at a tip **121***a* of the tongue **121**, the tongue **121** has an upwardly tapering portion **121***b* and downwardly tapering portion **121***b* that gradually taper the width of the tongue from a smaller width at the tip **121***a* to a portion **121***d* that has a larger, constant width. This constant width is equal to the constant-width inside of the receptacle **101**.

The socket **120** has an upper surface **120***a* and a lower surface **120***b*. A plurality (e.g., four) of pins **171***a*-**171***d* are disposed on the upper surface **100***a* for mating with openings (not shown) formed in the lower portion **142** (FIG. **3**) of the cleave holder **140** (FIG. **3**). The openings that formed in the lower portion **142** of the cleave holder **140** are complementary in shape and size to the shape and size of the pins **171***a*-**171***d*. A stop **172** (FIG. **5**) disposed at the back end of the slot **122** abuts the proximal end **152***a* of the spring **152** to prevent the proximal end **152***a* of the spring **152** from moving in the rearward direction of the socket **120** (i.e., in the direction opposite the direction of arrow **156**). This stop **172** enables the spring **152** to be loaded to exert the force on the module **1** (FIG. **3**) that urges the module **1** in the direction of arrow **156**. The module **1** sits on the upper surface **120***a* of the socket **120** and is urged forward by the spring **152** into contact with side arms **123** and **124** of the socket **100**. As will be described below in more detail, the arms **123** and **124** have tapered stops formed on their inner walls **123***a* and **124***a* (FIG. **5**), respectively, that prevent further forward movement of the module **1** in the direction of arrow **156** (FIG. **3**). One of these tapered stops **124***b* is visible in FIG. **5**. The inner walls **123***a* and **124***a* are identical to one another and are complementary in shape to the shapes of side chamfers **2***f* and **2***g* (FIG. **1**) disposed on opposite sides of the module housing **2**. As will be described below in more detail, these tapered stops engage the chamfers **2***f* and **2***g* to restrict the movement of the module **1** when it is in the forward position shown in FIG. **3**.

With reference again to FIG. **3**, when the sockets **100** and **120** are coarsely aligned with one another such that the tongue **121** and the receptacle **101** are in coarse alignment with one another (e.g., within 50 mils in any direction of precise alignment), continued movement of the sockets **100** and **120** toward one another will ultimately result in the sockets **100** and **120** fully mating with one another. In other words, the tapered surfaces of the tongue **121** and of the receptacle **101** allow for some misalignment of the sockets **100** and **120** (e.g., 50 mils of misalignment in any direction) while still ensuring that the tongue **121** and the receptacle **101** will engage one another and ultimately mate with one another. This allows the sockets **100** and **120** to blind mate with one another provided they are only misaligned with one another within some tolerance, e.g., 50 mils.

As the sockets **100** and **120** are coarsely aligned with one another and moved toward one another, the alignment features **10** of the male socket **1** will begin to initially engage the alignment features **21** of the female socket **20**. Even if the sockets **100** and **120** are misaligned within some tolerance, e.g., 50 mils, but close enough to one another that the modules **1** and **20** are in contact with one another, the alignment features **10** of module **1** will begin to engage the alignment features **21** of module **20**. Once the alignment features **10** and **21** begin to engage one another, continued movement of the sockets **100** and **120** toward one another will cause the alignment features **10** and **21** to continue to engage one another until they are in the fully-mated state. In the fully-mated state of the alignment features **10** and **21**, the modules **1** and **20** are in precise (i.e., fine) alignment with one another such that their optical pathways are precisely aligned. Thus, blind mating of the sockets **100** and **120** within the misalignment tolerance ultimately results in fine alignment of the modules **1** and **20**.

FIG. **6** illustrates a top view of the sockets **100**, **120** and the modules **1**, **20** shown in FIG. **3** in the fully-mated state. In FIG. **6**, top portions of the arms **103**, **104**, **123** and **124** have been removed to allow the interaction between the chamfers **2***g* of the modules **1** and **20** and the tapered stops **103***b*, **104***b*, **123***b* and **124***b* formed on the inner walls **103***a*, **104***a*, **123***a* and **124***a* of the arms **103**, **104**, **123** and **124**, respectively, to be clearly seen. With reference to FIG. **2**, the shape of the chamfers can be clearly seen by looking at chamfer **2***g*. The chamfer **2***g* thins in the Y and Z dimensions as it nears the front surface **2***c* of the module **20**. At the location where the chamfer **2***g* ends near the front surface **2***c*, the chamfer **2***g* converges in the Y and Z dimensions to an apex **2***g'*.

With reference again to FIG. **6**, the portions of the inner walls **103***a*, **104***a*, **123***a* and **124***a* that form the tapered stops **103***b*, **104***b*, **123***b* and **124***b*, respectively, are complementary in shape to the shapes of the respective chamfers **2***f* and **2***g*, but the chamfers **2***f* and **2***g* are slightly smaller in size than the respective tapered stops **103***b*, **104***b*, **123***b* and **124***b* in the X, Y and Z dimensions. This size difference allows some freedom of movement of the modules **1** and **20** relative to the sockets **120** and **100**, respectively, in the X, Y and Z dimensions as the sockets **100** and **120** and the modules **1** and **20** are engaging one another. The distal ends **151***b* and **152***b* of the springs **151** and **152**, respectively, urge the modules **1** and **20** toward one another causing their front surfaces **2***c* to come into contact with one another. The opposing forces provided by the springs **151** and **152** and the space in between chamfers **2***f* and **2***f* and the respective tapered stops **103***b*, **104***b*, **123***b* and **124***b* allow the modules **1** and **20** to float, or move, to a limited extent within their respective sockets **120** and **100** in the X, Y and Z directions, while also centering the modules **1** and **20** within their respective sockets **120** and **100** when the modules **1** and **20** are not in contact with one another.

The engagement of the tapered stops **103***b*, **104***b*, **123***b* and **124***b* with the respective chamfers **2***f* and **2***g* limits the extent to which the modules **1** and **20** are able to float, or move, within their respective sockets **120** and **100**. Allowing the modules **1** and **20** to float to a limited extent within the sockets **120** and **100**, respectively, ensures that the respective alignment features **10** and **21** will blindly engage one another and ultimately fully mate with one another when the respective sockets **100** and **120** are blind mated with one another.

FIG. **7** illustrates a top perspective view of an expanded portion of the view shown in FIG. **6** within the dashed circle labeled with reference numeral **190**. As the distal ends **151***b* and **152***b* of the springs **151** and **152** (FIG. **6**) urge the sockets **100** and **120** forward into abutment with one another, the chamfers **2***g* and **2***f* slide along the tapered stops **104***b* and **124***b*, respectively. When the front surfaces **2***c* of the modules **1** and **20** are not in contact with one another (FIG. **3**), the interaction of the tapered stops **104***b* and **124***b* with the chamfers **2***g* and **2***f*, respectively, directs the modules **20** and **1** in the Y direction indicated by arrow **191**. Likewise, on the opposite side of the sockets **100** and **120** (FIG. **6**), the interaction between the chamfers **2***f* and **2***g* and the tapered stops **103***b* and **123***b* (FIG. **6**), respectively, directs the modules **20** and **1** in the opposite Y direction indicated by arrow **192** (FIG. **7**). The combined effect of the chamfers **2***g* and **2***f* and the tapered stops **103***b*, **104***b*, **123***b* and **124***b* when the front surfaces **2***c* of the modules **1** and **20** are not in contact with one another is to align the modules **1** and **20** in the Y dimension within their respective sockets **120** and **100**. Because the shapes of the chamfers **2***g* and **2***f* and the tapered stops **103***b*, **104***b*, **123***b* and **124***b* are also complementary in the Z dimension, the interaction between the chamfers **2***g* and **2***f* and the tapered stops **103***b*, **104***b*, **123***b* and **124***b* also has the effect of aligning the modules **1** and **20** within their respective sockets **120** and **100** in the Z dimension when the front surfaces **2***c* of the modules **1** and **20** are not in contact with one another.

When the front surfaces **2***c* of the modules **1** and **20** are not in contact with each other as shown in FIG. **3**, the modules **1** and **20** are slightly proud of their respective sockets **120** and **100**. In other words, the front surfaces **2***c* of the modules **1** and **20** are slightly forward of their respective sockets **120** and **100** in the directions indicated by arrows **156** and **155** (FIG. **3**), respectively, when the front surfaces **2***c* of the modules **1** and **20** are not in contact with each other. The springs **151** and **152** urge the modules **20** and **1**, respectively, into these forward positions. When the front surfaces **2***c* of the modules **1** and **20** are pressed against one another as shown in FIGS. **6** and **7**, the forces exerted by the springs **152** and **151** on the modules **1** and **20**, respectively, and the space in between the chamfers **2***g* and **2***f* and the respective tapered stops **103***b*, **104***b*, **123***b* and **124***b* allow the modules **1** and **20** to float, or move, to a limited degree within their respective sockets **120** and **100**. However, the forces exerted by the springs **151** and **152** on the modules **20** and **1**, respectively, and the interaction between the chamfers **2***g* and **2***f* and the respective tapered stops **103***b*, **104***b*, **123***b* and **124***b* also limit the freedom of movement of the modules **1** and **20** within their respective sockets **120** and

100 to predetermined alignment tolerances. This limited freedom of movement within predetermined alignment tolerances ensures that the alignment features **10** and **21** find one another, begin to engage one another and ultimately fully mate with one another to bring the modules **1** and **20** into precise optical alignment with one another.

The sockets **100** and **120** are typically mounted on respective structures, such as cross bar of a rack and a printed circuit board (PCB) of a box that is designed to be inserted into the rack. FIGS. **8**A and **8**B are top and bottom perspective views, respectively, of the male socket **120** shown in FIGS. **3** and **5** mounted on a PCB **200** of a box (not shown) that is designed to be inserted into a slot (not shown) of a rack (not shown). FIGS. **9**A and **9**B illustrate side cross-sectional perspective views of a cross bar **220** of a rack (not shown) having a mounting frame **230** secured thereto by a bridle **240** of the mounting frame **230**. The side cross-sectional views of the socket **100** shown in FIGS. **9**A and **9**B are taken along line A-A' of FIG. **4**. In FIG. **9**A, the socket **100** is shown as it is about to be mounted on the mounting frame **230**, whereas FIG. **9**B shows the socket **100** after it has been mounted on the mounting frame **230**. FIG. **10** is a perspective view of the mounting frame **230** shown in FIGS. **9**A and **9**B with the socket **100** and the cross bar **220** removed.

With reference to FIGS. **8**A and **8**B, for exemplary purposes it will be assumed that the PCB **200** is contained in a box (not shown) that has mating features on it and that the slot of the rack that includes cross bar **220** has mating features on it. These mating features may be, for example, guide rails formed in the slot and bottom side edges of the box. In this exemplary case, when the box is being installed in the rack, the bottom side edges of the box are guided by the guide rails of the slot. Such mating features for installing boxes in slots of racks are well known in the art, and therefore will not be described herein in the interest of brevity.

With reference to FIGS. **9**A and **9**B, the cross bar **220**, the mounting frame **230** and the female socket **100** mounted thereon are typically disposed at the back of the slot. The female socket **100** is secured to the mounting frame **230** (FIG. **9**B) in a predetermined position and orientation relative to the cross bar **220**, and therefore the module **20** is in a predetermined position and orientation relative to the cross bar **220**.

With reference again to FIGS. **8**A and **8**B, the male socket **120** is disposed at a predetermined location and with a predetermined orientation on the upper surface **200***a* of the PCB **200**. A male keying feature **201** (FIG. **8**B) of the socket **120** is complementary in shape and size to a female keying feature **211** (FIG. **8**B) formed in the edge of the PCB **200** on which the socket **120** is mounted. When the keying features **201** and **211** are engaged with one another as shown in FIG. **8**B, the socket **120** is in its predetermined position and orientation on the PCB **200**. When the socket **120** is in its predetermined position and orientation on the PCB **200**, the socket **120** is necessarily in a predetermined position and orientation relative to the box in which it is contained due to the fact that the PCB **200** is mounted within the box in a predetermined position and with a predetermined orientation relative to the box.

The edge of the PCB **200** (FIGS. **8**A and **8**B) on which the male socket **120** is mounted is typically adjacent the back of the box and disposed through a receptacle (not shown) formed in the back of the box. When the box is inserted into the slot and pushed toward the back of the slot until the back of the box comes into contact with the cross bar **220** (FIG. **9**B), the female and male sockets **100** and **120** will engage one another and the modules **20** and **1** will engage one another in the manner described above with reference to FIGS. **1**-**7**. Because boxes and racks can be manufactured with very tight tolerances, blind mating of the box with the slot will place the sockets **100** and **120** well within the alignment tolerance needed to allow blind mating of the sockets **100** and **120** with one another. In turn, the blind mating of the sockets **100** and **120** will result in blind mating of the modules **1** and **20** in the manner described above with reference to FIGS. **1**-**7**.

With reference to FIG. **10**, the mounting frame **230** is made of a resilient material such as sheet metal, for example, to provide it with spring characteristics. The spring characteristics allow the socket **100** (FIG. **9**B) to float, or move, to a limited extent relative to the cross bar **220**. The extent of float that the mounting frame **230** allows will depend on the maximum amount of misalignment that there can be between the sockets **100** and **120** while still allowing them to engage one another and ultimately fully mate. For example, if the largest amount of misalignment that there can be between the sockets **100** and **120** while still allowing them to engage one another is ±50 mils in the X, Y and Z dimensions, then the maximum amount of float that the mounting frame **230** will allow is also ±50 mils in the X, Y and Z dimensions. Similarly, the extent of float that the sockets **100** and **120** can have will depend on the maximum amount of misalignment that there can be between the modules **1** and **20** while still allowing them to engage one another and ultimately fully mate. For example, if the largest amount of misalignment that there can be between the modules **1** and **20** while still allowing them to engage one another is ±50 mils in the X, Y and Z dimensions, then the maximum amount of float that the sockets **100** and **120** can have is also ±50 mils in the X, Y and Z dimensions.

With reference to FIGS. **9**A and **9**B, the bridle **240** of the mounting frame **230** is fixedly secured to the cross bar **220** by rivets **241**, although a variety of other fastening devices or materials may be used for this purpose. The mounting frame **230** has a spring socket **242** on which the socket **100** (FIG. **9**B) is seated. As can be seen in FIG. **9**B, the spring socket **242** has a curved front end **243** and a curved back end **244**. The spring socket **242** has a male locking feature **245** on its lower surface that engages a female locking feature **246** formed in the socket **100** to lock the socket **100** in place on the mounting frame **230**. The bottom surface of the curved front end **243** of the spring socket **242** engages an indented region **247** formed in the socket **100**.

With reference to FIG. **10**, it can be seen that there is a pair of the locking features **245**. Although it is not visible in the side perspective view shown in FIG. **9**B, there is also a pair of the locking features **246** formed in the socket **100**. The spring socket **242** (FIG. **10**) is mechanically coupled to the bridle **240** by rectangular spring arms **248** and **249**. These spring arms **248** and **249** allow the spring socket **242** to float, which, in turn, allows the socket **100** to float as the tongue **121** of the socket **120** engages the receptacle **101** of the socket **100**.

It can be seen from the above description of the illustrative embodiments that a combination of features of the modules **1** and **20**, the sockets **100** and **120** and the mounting frame **230** allow the socket **100** to float to a limited, predetermined extent relative to the mounting frame **230** and allow the modules **1** and **20** to float to a limited, predetermined extent relative to the sockets **120** and **100**, respectively. This limited, predetermined floating allows the mating features **101** and **121** of the sockets **100** and **120**, respectively, to blindly mate with one another and allows the mating features **10** and **21** of the modules **1** and **20**, respectively, to blindly mate with one another. Thus, as described above, installing a box into a slot of a rack will result in the modules **1** and **20** engaging one another and will result in the optical pathways of the modules **1** and **20** being brought into precise optical alignment with one another.

It should be noted that the invention has been described with reference to illustrative, or exemplary, embodiments in order to demonstrate the principles and concepts of the invention. As will be understood by those of skill in the art, the invention is not limited to the illustrative embodiments described herein. For example, the features that allow the floating aspects to be achieved are not limited to the features that have been described herein. Persons skilled in the art will understand, in view of the description provided herein, that a variety of mechanism can be used to achieve the floating aspects described herein. Persons skilled in the art will understand the manner in which these and other modifications may be made to the embodiments described herein and that all such modifications are within the scope of the invention.

What is claimed is:

1. A first socket having a first multi-optical fiber connector module mounted thereon, the first socket being adapted to mate with a second socket having a second multi-optical fiber connector module mounted thereon such that mating of the first and second sockets with one another results in mating of the first and second connector modules with one another, the first socket comprising:

a first socket housing having at least an upper surface, a lower surface, a first end, and a second end, wherein the first multi-optical fiber connector module is mounted on the upper surface of the first socket housing in a predetermined position and orientation relative to the first socket housing, wherein the first multi-optical fiber connector module has a first connector module housing that has at least a first passive fine alignment feature formed thereon; and

at least a first passive coarse alignment feature formed on the first socket housing, the first passive coarse alignment feature being configured to engage and ultimately fully mate with a second passive coarse alignment feature formed on a second socket housing of the second socket, and wherein engagement of the first and second passive coarse alignment features of the first and second socket housings with one another brings the first and second passive fine alignment features of the first and second connector module housings into coarse alignment with one another, and wherein full mating of the first and second passive coarse alignment features with one another results in full blind mating of the first and second fine alignment features with one another to place the first and second fine alignment features in a fully-mated state, and wherein when the first and second fine alignment features are in the fully-mated state, optical pathways of the first connector module are in precise alignment with respective optical pathways of the second connector module.

2. The first socket of claim **1**, wherein the first connector module housing is held in a floating arrangement on the first socket housing that allows the first connector module housing to move to a limited extent relative to the first socket housing, and wherein the floating arrangement ensures that engagement of the first and second passive coarse alignment features of the first and second socket housings with one another will bring the first and second passive fine alignment features of the first and second connector module housings into coarse alignment with one another.

3. The first socket of claim **2**, wherein the floating arrangement includes first and second arms disposed on the front end of the first socket housing that engage the first connector module housing and a spring in contact with the first socket housing and with the first connector module housing, and wherein the spring applies a force to the first connector module housing that urges the first connector module housing into the first and second arms.

4. The first socket of claim **3**, wherein the first and second arms have first and second inner walls, respectively, that are complementary in shape to first and second features, respectively, formed on opposite sides of the first connector module housing.

5. The first socket of claim **4**, wherein when the first and second inner walls are engaged with the first and second features, respectively, formed on the opposite sides of the connector module housing, some space exists in between the first and second inner walls and the first and second features, respectively, and wherein the space provides the first and second features will freedom to move to a limited extent relative to the first and second inner walls, respectively, and wherein the freedom of movement of the first and second features relative to the first and second inner walls, respectively, in combination with the spring force applied to the first connector module housing provides the first connector module housing with freedom to move to a limited extent relative to the first socket housing.

6. The first socket of claim **1**, further comprising:

a cleave holder mounted on the upper surface of the first socket housing near the second end of the first socket housing, the cleave holder being adapted to clamp optical fiber cables that contain optical fibers that are attached on ends thereof to the first connector module housing, wherein the cleave holder is adapted to provide strain relief for the optical fibers.

7. The first socket of claim **1**, wherein the first passive coarse alignment feature is a receptacle formed in the first end of the first socket housing, and wherein the second passive coarse alignment feature is a tongue formed on the second socket housing that is complementary in shape to a shape of an inner surface of the receptacle.

8. The first socket of claim **7**, wherein the first passive fine alignment feature of the first connector module housing comprises a pair of tapered openings formed in a front face of the first connector module housing, and wherein the second passive fine alignment feature of the second connector module housing comprises a pair of tapered pins disposed on a front face of the second connector module housing, the tapered pins having outer surfaces that are complementary in shape to inner surfaces of the tapered openings.

9. The first socket of claim **7**, wherein the first passive fine alignment feature of the first connector module housing comprises a pair of tapered pins disposed on a front face of the first connector module housing, and wherein the second passive fine alignment feature of the second connector module housing comprises a pair of tapered openings formed in a front face of the second connector module housing, the tapered pins having outer surfaces that are complementary in shape to inner surfaces of the tapered openings.

10. A system for blind mating multi-optical fiber connector modules, the system comprising:

a first structure;

a mounting frame secured to the first structure, the mounting frame having spring properties;

a first socket mounted on the mounting frame, the first socket having a first socket housing having at least an upper surface, a lower surface, a first end, and a second end, and wherein the first socket housing has at least a first passive coarse alignment feature thereon;

a first multi-optical fiber connector module mounted on the upper surface of the first socket housing, wherein the first multi-optical fiber connector module has a first connector module housing that has at least a first passive fine alignment feature thereon;

a first plurality of optical fibers having first ends that are secured to the first connector module housing;

a second structure;

a second socket mounted on the second structure, the second socket having a second socket housing having an upper surface, a lower surface, a first end and a second end, the second socket housing having a second passive coarse alignment feature thereon that is mated with the first passive coarse alignment feature;

a second multi-optical fiber connector module mounted on the upper surface of the second socket housing, wherein the second multi-optical fiber connector module has a second connector module housing that has at least a second passive fine alignment feature thereon that is blind mated with the first passive fine alignment feature when the first and second coarse alignment features are mated with one another, and wherein when the first and second fine alignment features are mated with one another, optical pathways of the first connector module are in precise alignment with respective optical pathways of the second connector module; and

a second plurality of optical fibers having first ends that are secured to the second connector module housing.

11. The system of claim **10**, wherein the initial engagement of the first and second passive coarse alignment features of the first and second socket housings with one another brings the first and second passive fine alignment features of the first and second connector module housings into coarse alignment with one another, and wherein the mating of the first and second passive coarse alignment features with one another results in the mating of the first and second fine alignment features with one another.

12. The system of claim **11**, wherein the spring properties of the mounting frame allow the first socket to move to a limited extent relative to the mounting frame as the first and second passive coarse alignment features mate with one another.

13. The system of claim **12**, wherein the first connector module housing is held in a floating arrangement on the first socket housing that allows the first connector module housing to move to a limited extent relative to the first socket housing, and wherein the floating arrangement ensures that mating of the first and second passive coarse alignment features with one another brings the first and second passive fine alignment features of the first and second connector module housings into coarse alignment with one another.

14. The system of claim **13**, wherein said floating arrangement is created in part by first and second arms disposed on the front end of the first socket housing that engage the first connector module housing and a spring that is in contact with the first socket housing and with the first connector module housing, wherein the spring applies a force to the first connector module housing that urges the first connector module housing into contact with the first and second arms.

15. The system of claim **14**, wherein the first and second arms have first and second inner walls, respectively, that are complementary in shape to first and second features, respectively, formed on opposite sides of the first connector module housing, and wherein the first and second inner walls are engaged with the first and second features, respectively, formed on the opposite sides of the connector module housing, and wherein some space exists in between the first and second inner walls and the first and second features, respectively, and wherein the space provides the first and second features with freedom to move to a limited extent relative to the first and second inner walls, respectively, and wherein the limited freedom of movement of the first and second features relative to the first and second inner walls, respectively, in combination with the spring force applied to the first connector module housing provides the first connector module housing with freedom to move to a limited to a limited extent relative to the first socket housing.

16. The system of claim **10**, further comprising:

a cleave holder mounted on the upper surface of the first socket housing near the second end of the first socket housing, the cleave holder clamping a portion of at least one optical fiber cable that contains the first plurality of optical fibers, wherein the cleave holder provides strain relief for the first plurality of optical fibers.

17. The system of claim **10**, wherein the first passive coarse alignment feature is a receptacle formed in the first end of the first socket housing, and wherein the second passive coarse alignment feature is a tongue formed on the second socket housing that is complementary in shape to a shape of an inner surface of the receptacle.

18. The system of claim **17**, wherein the first passive fine alignment feature of the first connector module housing comprises a pair of tapered openings formed in a front face of the first connector module housing, and wherein the second passive fine alignment feature of the second connector module housing comprises a pair of tapered pins disposed on a front face of the second connector module housing, the tapered pins having outer surfaces that are complementary in shape to inner surfaces of the tapered openings.

19. The system of claim **17**, wherein the first passive fine alignment feature of the first connector module housing comprises a pair of tapered pins disposed on a front face of the first connector module housing, and wherein the second passive fine alignment feature of the second connector module housing comprises a pair of tapered openings formed in a front face of the second connector module housing, the tapered pins having outer surfaces that are complementary in shape to inner surfaces of the tapered openings.

20. The system of claim **10**, wherein the first structure is a circuit board located inside of a box having an opening therein, and wherein the second structure is a cross bar of a slot of a rack, wherein the box is installed in the slot, and wherein the first ends of the first and second sockets and front faces of the first and second multi-optical fiber connector modules are disposed adjacent the opening of the box to allow the first and second passive coarse alignment features and the first and second passive fine alignment features to mate with one another, respectively.

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